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MEMORANDUM

Subject: Annual Report
ULI: FY2012

This document provides a annual report on the project "Advanced Digital Signal Processing" covering FY2012.

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Award Information

Award Number	N000141110371
Title of Research	Advanced Digital Signal Processing for Hybrid Lidar
Principal Investigator	William D. Jemison
Organization	Clarkson University

Technical Section

Technical Objectives

The technical objective of this project is the development and evaluation of various digital signal processing (DSP) algorithms that will enhance hybrid lidar performance. Practical algorithms must be developed taking into account the underwater propagation channel and the processing requirements for each algorithm as shown in Figure 1.

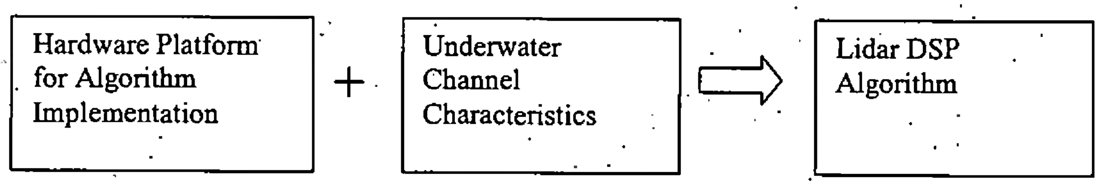


Figure 1. The development of lidar DSP algorithms must take into account hardware implementation and underwater channel characteristics.

Technical Approach

A significant challenge in hybrid lidar-radar is optical absorption and scattering. The absorption of the light photons by the molecules in the water channel contributes to a decrease in the total signal level collected at the receiver. This unwanted phenomenon can be reduced by selecting the wavelength of the laser light to be in the blue-green region. Backscattering occurs when transmitted light signal reflects off a water particulate and reaches the detector without first reaching the object. Thus, backscattered light contains no information regarding the object and it reduces the image contrast and resolution as well as the object ranging measurement accuracy. There have been various methods that attempt to reduce the backscatter. One method is to increase the modulation frequency beyond 100MHz and another is to use a dual high-frequency (>100MHz) approach that uses high speed modulation to help suppress backscatter while also providing an unambiguous range measurement. In general, it is desired to determine which combination of Radio Frequency (RF) modulation frequencies, modulation waveforms, and signal processing algorithms help improve hybrid lidar-radar performance in a variety of underwater environments.

The approach is to focus on the optical proximity detector that is being developed with ONR funding. The goal is to replace analog hardware with digital components to benefit from the advantages offered with digital hardware and signal processing, including better sensitivity due to large dynamic range digitizers and lossless digital demodulation and filtering, reconfigurability via software to improve sensor adaptability in different environments and for multiple applications, and real-time processing for instant feedback.

This year we developed a new backscatter reduction technique that leverages spatial filtering techniques developed to enhance the performance of through the wall imaging (TTWI) radar. The technique was validated using both simulated and experimental data. Simulated data was generated using Rangfinder, a lidar simulation tool developed by the Navy. This data was then processed using the spatial filter and ranging performance between the filtered and unfiltered data were compared. In addition, experimental ranging data taken in a Navy test tank were also used to validate the filter and ranging measurement results with and without the application of the spatial filter in order to compare the performance improvements that can be obtained for various turbidities and laser modulation frequencies.

Progress Statement Summary

A new radar approach was identified to help suppress unwanted backscatter 'clutter' from the underwater environment and enhance the sensitivity of the hybrid lidar-radar system. This approach is based on that which has been developed for Through-the-wall Radar Imaging (TWRI) to view objects behind a wall. In TWRI, the 'clutter' signal is that which emanates from the wall. This 'clutter' signature remains relatively constant in both phase and frequency as the radar antenna is moved along the wall. However, a weak return from an object behind the wall will have a phase and/or frequency signature that changes as the antenna changes position relative to the object. These differences between the radar signatures of the constant 'clutter' signal and the variable target signal are used to enhance the sensitivity of the radar system to detecting an otherwise obscured object. The application of this radar technique to the lidar system operating in water comes from relating the wall return to the backscatter 'clutter' from the water environment. The amplitude and phase of the water-backscattered hybrid lidar-radar signal is relatively constant while the signal reflected from an underwater object will vary in amplitude and phase as its position changes relative to the transmitter/receiver. The TWRI technique was applied to both simulated and experimental data through the use of a simple delay line filter. This approach subtracts the detected signal from a previously detected signal that is delayed in space by some dz value. When this dz corresponds to a half wavelength of the radar modulation envelope, the backscatter 'clutter' signals are subtracted while the target-reflected returns are added. Results from analyzing both simulated and experimental data show that this delay line approach is very effective in suppressing backscatter clutter and improving the ability of the hybrid lidar-radar system to measure the range to an underwater object in challenging turbid water environments.

Progress

The graduate student sponsored by this ULI project, Mr. Paul Perez, worked as a NREIP intern at the Naval Air Station in Patuxent River, MD during the summer of 2012. The focus of Mr. Perez's work was to implement a spatial frequency filter to process experimental data taken earlier in the year for the ONR-funded 'Optical Proximity Sensor for Underwater Applications' project. The approach was to use a single delay line filter due to its simplicity and ease of implementation. The experimental data was obtained by modulating a laser at high (>100MHz) frequencies and using the phase shift between the transmitted and detected signals to measure target range. The data was collected in different water environments (different water clarities) and at different modulation frequencies (140, 160, and 180MHz). The first step was to review the data collection and processing procedure with Mr. Perez so that he had a clear understanding of how the data was obtained. Mr. Perez then wrote a Matlab program to read the experimental data (magnitude and phase for different target positions), construct a complex signal from these values, apply the single delay line filter with the optimal delay, and then compute a new magnitude and phase from this filtered data. The phase was then used to compute a 'filtered' target range. Results for modulation frequencies of 140MHz and 160MHz in clean (c = 0.08/m) water are shown in Figures 1a and 1b, respectively. Here the 'before filter' and 'after filter' data are very similar since the water turbidity is low and backscattered light does not affect the sensor's ability to measure target range. However, for the more turbid water data in Figure 2 (c = 2.5/m), there does appear to be an improvement in the measured target range when the filter is applied – particularly in the 140MHz data (Figure 2a).

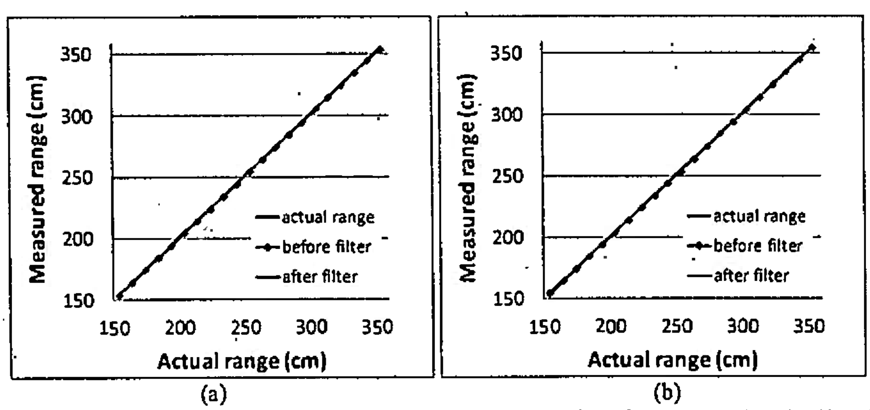


Figure 1. Measured target range vs. actual target range for modulation frequencies of 140MHz (a) and 160MHz (b) in clean water (c=0.08/m). The 'before filter' data corresponds to the experimental data that was used as an input to the single delay line spatial filter, and the 'after filter' data is the resulting range after the spatial filter is applied.

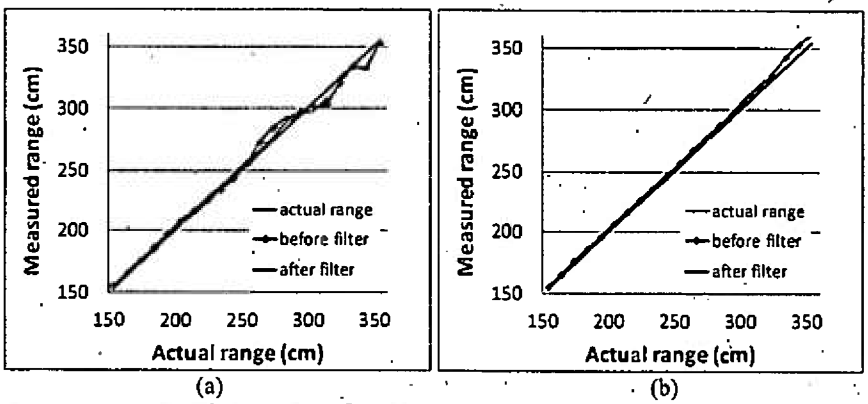


Figure 2. Measured target range vs. actual target range for modulation frequencies of 140MHz (a) and 160MHz (b) in turbid water (c=2.5/m). The 'before filter' data corresponds to the experimental data that was used as an input to the single delay line spatial filter, and the 'after filter' data is the resulting range after the spatial filter is applied.

A clear advantage of the spatial filter is observed when the 'dual frequency' approach is evaluated. The purpose of the 'dual frequency' scheme is to reduce the range ambiguity associated with modulating the laser at high (>100MHz) frequencies by modulating the laser at two high frequencies (>100MHz) that are separated in frequency by some Δf. The range ambiguity is then determined by this frequency difference. The results obtained in clean water (c = 0.08/m) and turbid water (c = 2.5/m) for modulation frequencies of 160MHz and 140MHz (Δf=20MHz) are shown in Figures 3a and 3b, respectively. The resulting error between the measured and actual target range for the data in Figure 3 is shown in Figure 4. Here it is clear that using the spatial filter for the dual frequency approach has a clear advantage when operating in turbid water. For example, the range error at a target position of 274cm is reduced from 47cm to 3cm when applying the spatial frequency filter to turbid water data (Figure 4b). Future work will focus on evaluating more sophisticated spatial frequency filters and applying them to model and experimental data obtained in FY13.

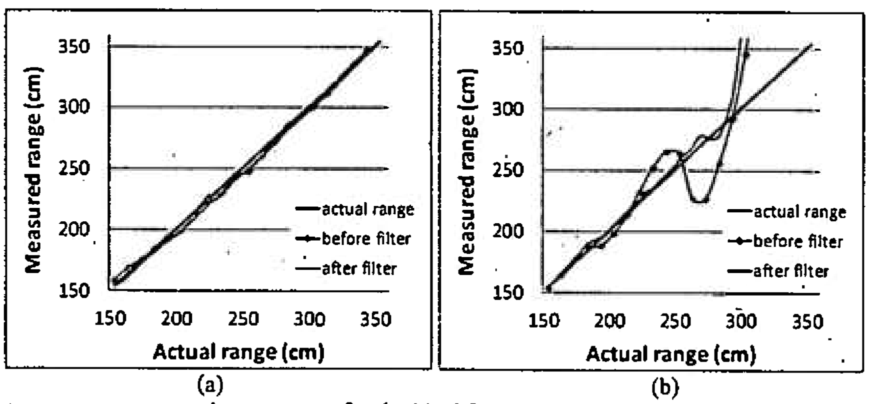


Figure 3. Measured target range vs. actual target range for the 'dual frequency' approach using modulation frequencies of 140MHz and 160MHz in clean water (c=0.08/m)(a) and turbid water (c=2.5/m)(b). The 'before filter' data corresponds to the experimental data that was used as an input to the single delay line spatial filter, and the 'after filter' data is the resulting range after the spatial filter is applied.

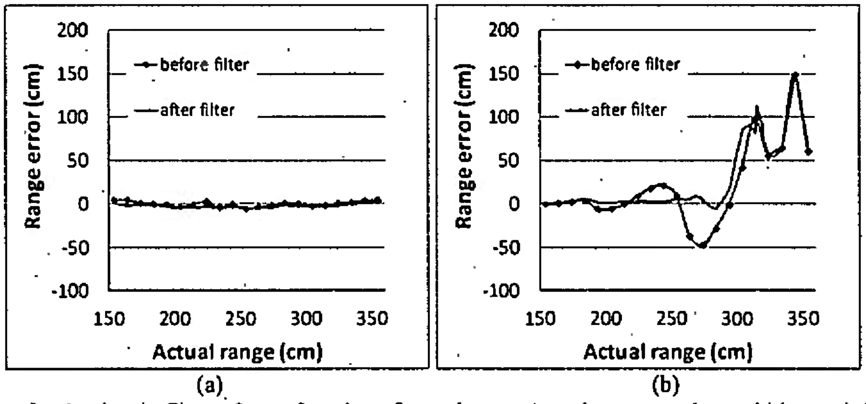
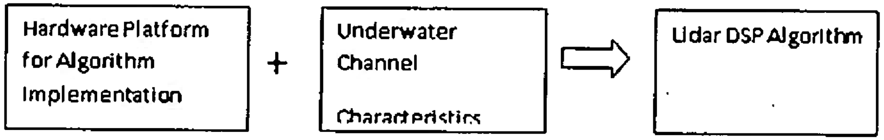


Figure 4: Range error for the data in Figure 3 as a function of actual range (a – clean water, b – turbid water). The 'before filter' data corresponds to the experimental data that was used as an input to the single delay line spatial filter, and the 'after filter' data is the resulting range after the spatial filter is applied.

Advanced Digital Signal Processing for Hybrid Lidar N000141110371

Objective:

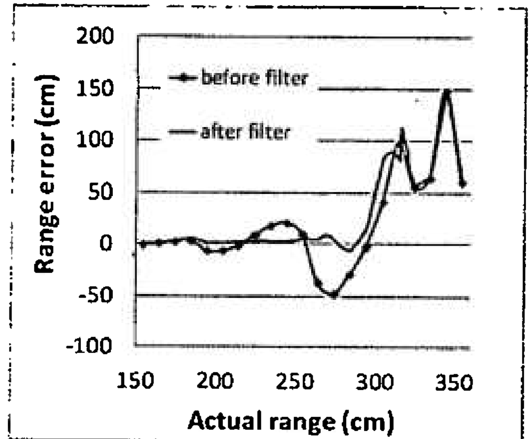
- Develop and evaluate various digital signal processing (DSP) algorithms that will enhance hybrid lidar performance.



Approach:

- Account for both practical hardware implementation and realistic underwater propagation characteristics
- Leverage existing work on proximity detection
- Use a combination of simulated and experimental lidar data to validate algorithms
- Leverage techniques developed for radar to the extent possible

Figure: Range error as a function of range for dual frequency hybrid lidar in turbid water with and without spatial filtering. The spatial filter reduces the range error significantly.



Scientific or Naval Impact/ Results:

- Preliminary results from the newly developed spatial filter technique show significant reduction in range error in turbid water for dual frequency hybrid lidar.
- For example, the range error at a target position of 274cm is reduced from 47cm to 3cm
- Processing necessary to achieve this results in minimal which lends itself to practical application.